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(54) Abstract Title: **Marine electromagnetic measurement system**

(57) A sea-floor electromagnetic measurement device (10) for obtaining underwater magnetotelluric (MT) measurements of earth formations includes a central structure (12) with arms (14) pivotally attached thereto. The pivoting arms enable easy deployment and storage of the device. Electrodes (16A-D) and magnetometers (18A, B) are attached to each arm for measuring electric and magnetic fields respectively, the magnetometers being distant from the central structure such that magnetic fields present therein are not sensed. A method for undertaking sea floor measurements includes measuring electric fields at a distance from the structure (12) and measuring magnetic fields at the same location.

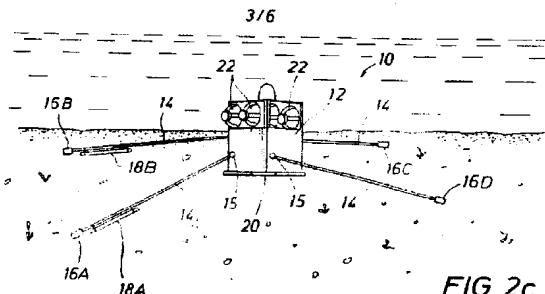
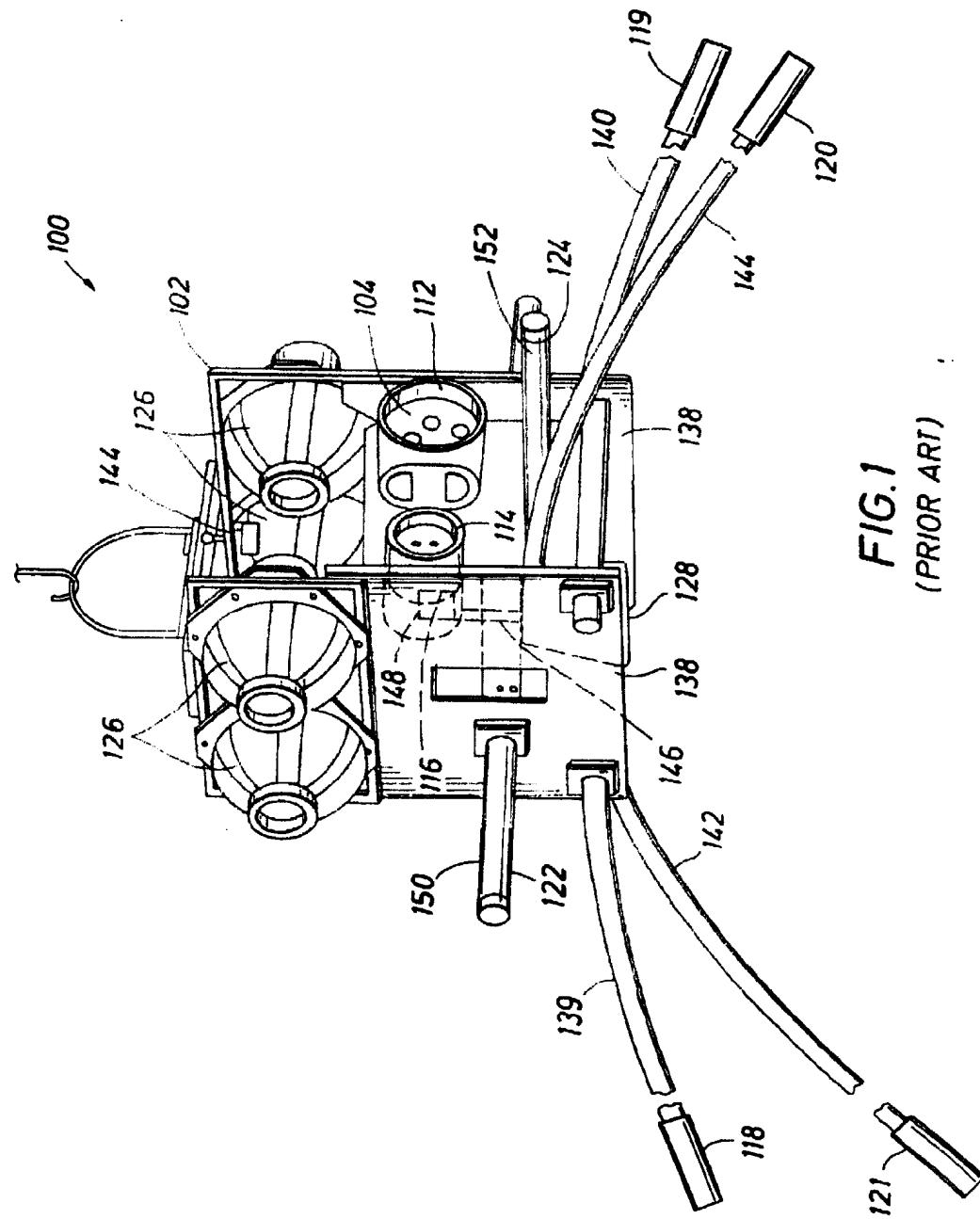


FIG. 2c

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FIG. 2a

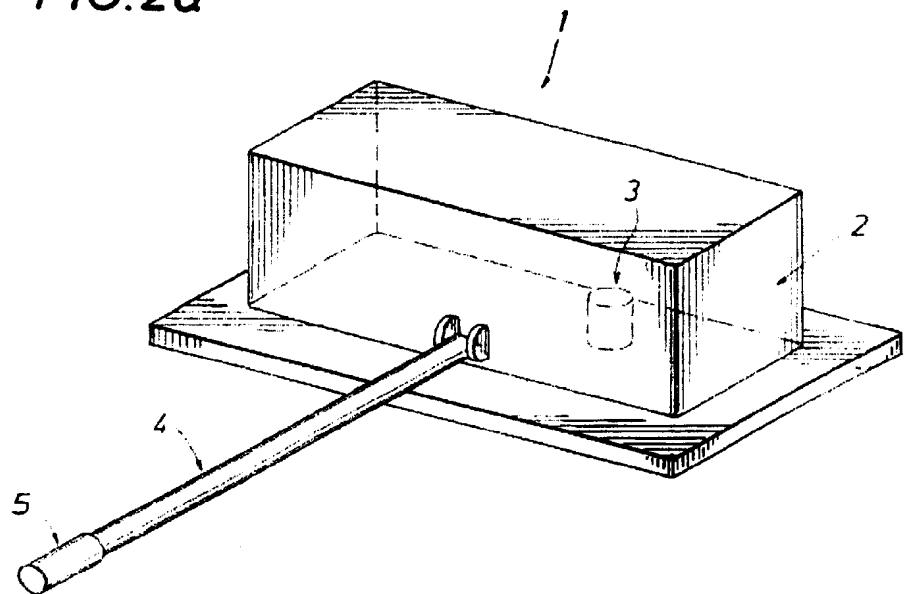
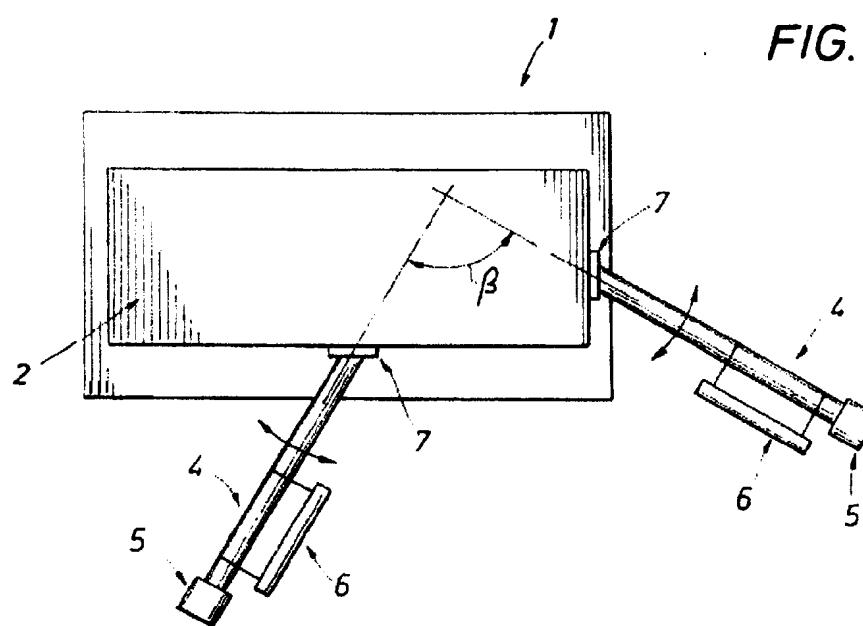


FIG. 2b



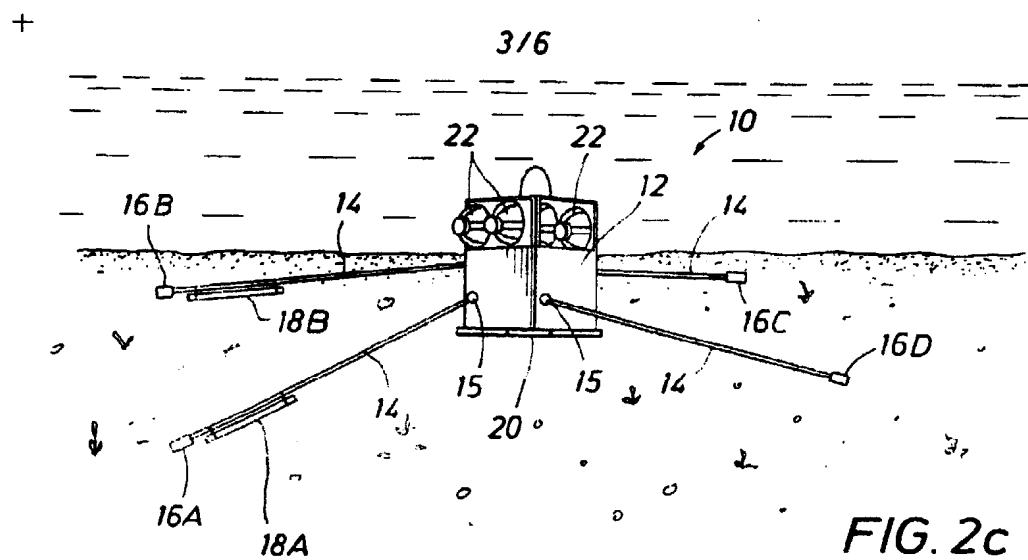


FIG. 2c

FIG. 3

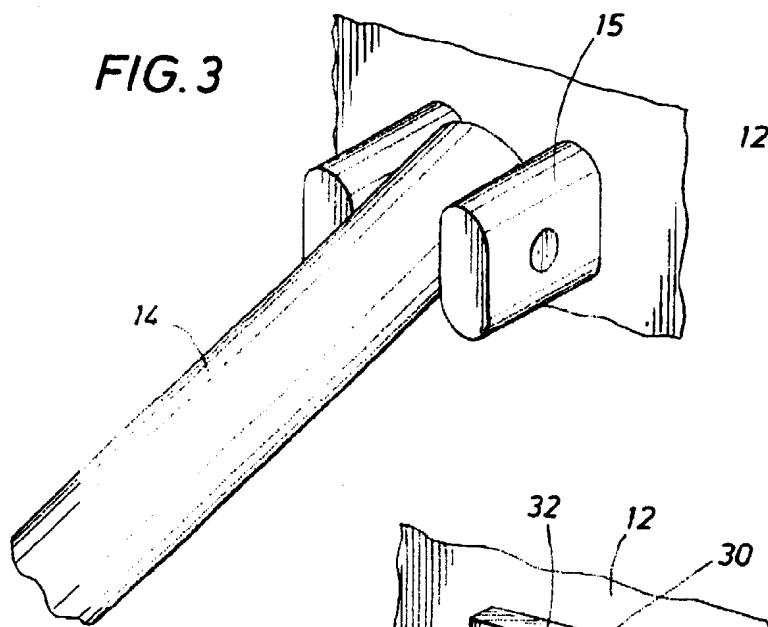
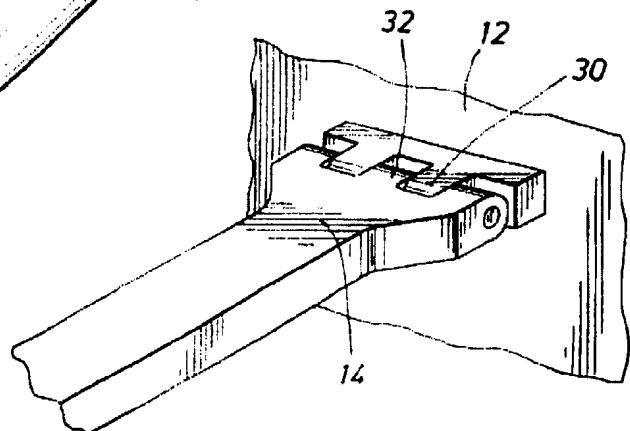


FIG. 4



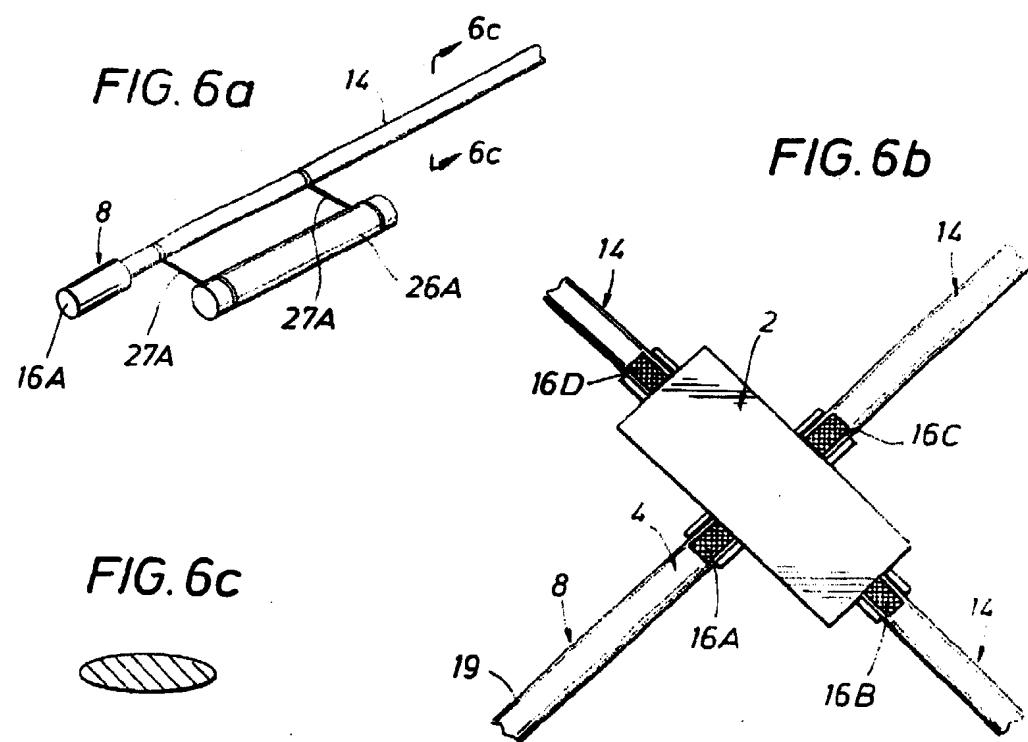
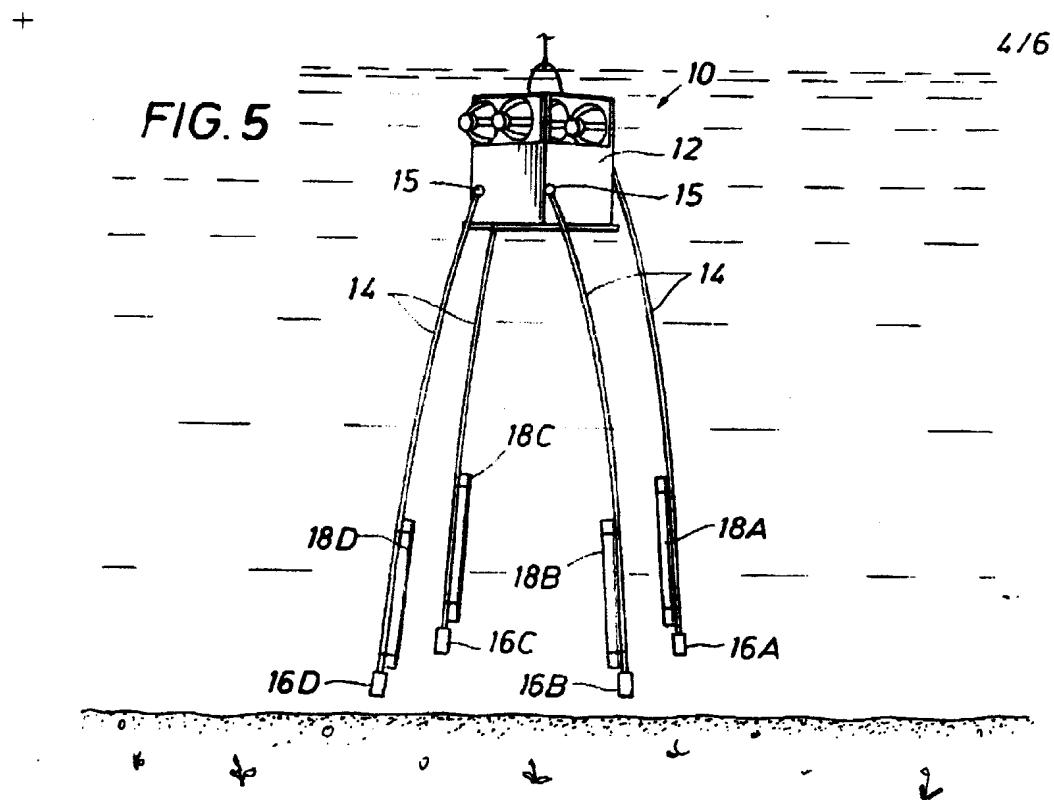


FIG. 7

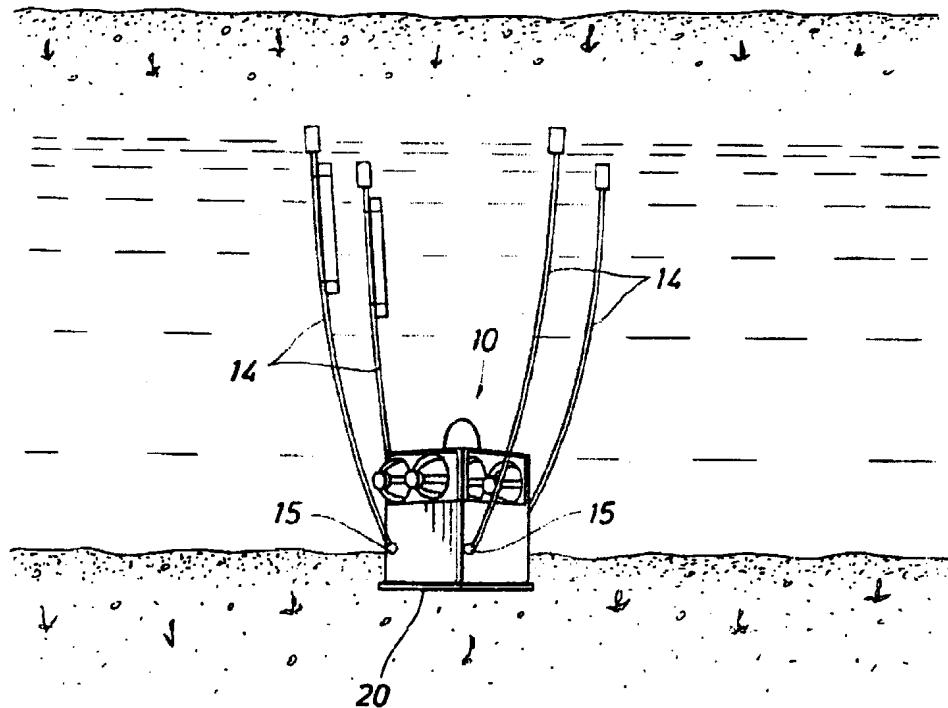
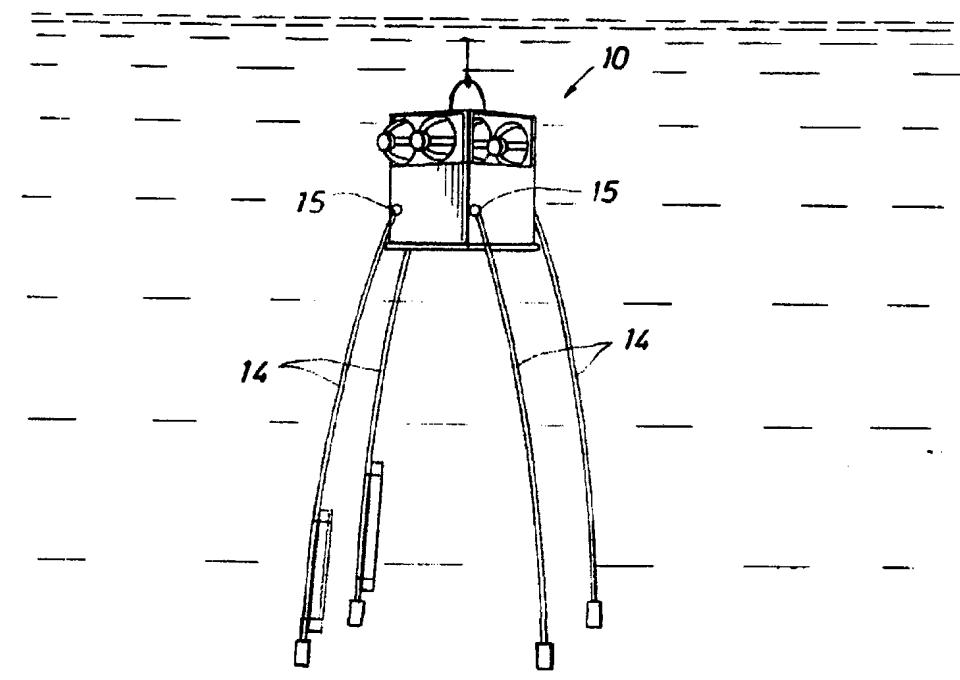


FIG. 8

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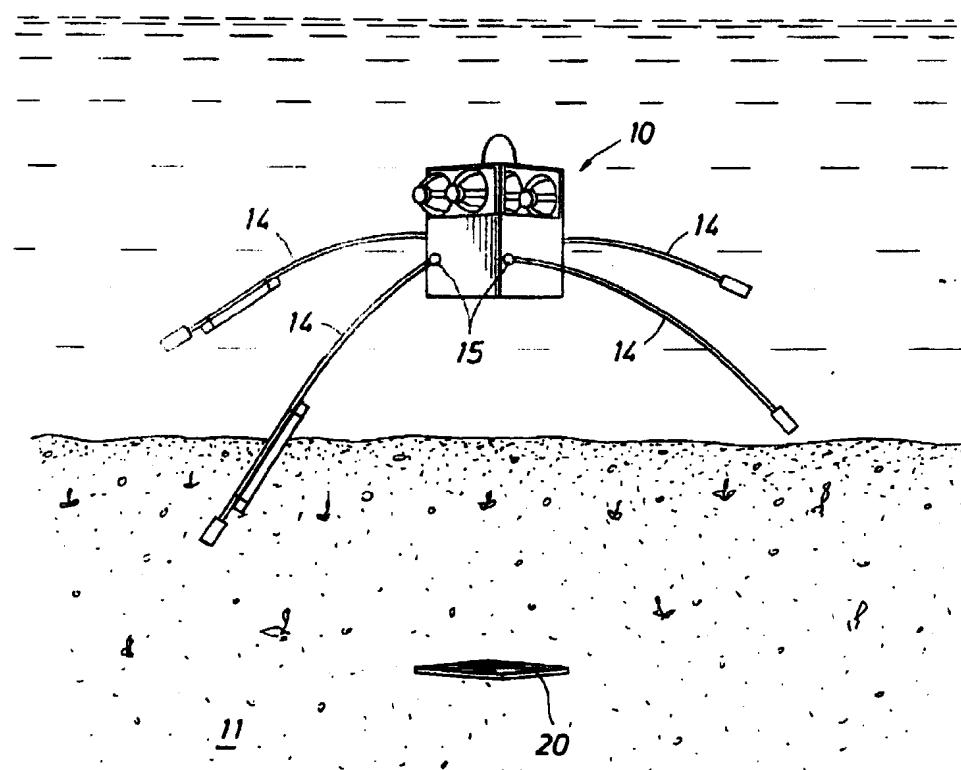


FIG.9

**MARINE ELECTROMAGNETIC MEASUREMENT SYSTEM****Background of Invention****Field of the Invention**

The invention relates generally to subsea exploration systems. More specifically, the invention relates to a marine electromagnetic measurement system and a method of deploying and retrieving the same. One application for electromagnetic measurement systems is as a marine magnetotelluric receiver.

**Background Art**

Magnetotelluric (MT) measurements are used to compute an electromagnetic impedance of selected earth formations. MT measurements are especially useful in regions where seismic imaging is inappropriate. For example, MT exploration is useful when evaluating geologic formations such as salts and carbonates. Salts, carbonates, and other particular formations may scatter seismic energy when seismic energy is propagated through them because of large velocity contrasts and inhomogeneties located within these formations, whereas the electromagnetic energy of the MT source fields propagates through these layers with less distortion. The MT method measures variations in the earth's magnetic and electric fields and does not use seismic energy to determine formation characteristics.

The MT method is typically used to measure an electromagnetic impedance as a function of frequency. Lower frequency provides a greater depth of penetration. The measured impedance may be transformed into an apparent resistivity and/or conductivity of the selected formations. Measuring impedance at several locations and at various frequencies enables a determination of resistivity and/or conductivity as a function of both depth and horizontal position. Therefore, the MT method may be used to evaluate formation resistivity over large areas of the seafloor. The formation resistivities of the various formations in a selected area may then be analyzed to determine the formation geometry, the presence or absence of hydrocarbons in selected formations, and the like.

The MT method is a passive method that uses natural variations in the earth's magnetic field as an energy source. The MT method includes a subsea system that detects orthogonal magnetic and electric fields proximate the seafloor to define a surface impedance. The surface impedance, as described above, may be measured over a broad range of frequencies and over a large area where layered formations act in a manner analogous to segments of an electrical transmission line. An MT method that operates according to the principles described above is generally disclosed in U.S. Patent No. 5,770,945 issued to Constable. This type of electromagnetic receiver can also be used to record electromagnetic signals which originated from various kinds of transmitter systems such as a towed cable bipole or magnetic loop source.

In addition the receivers could be used to detect electromagnetic radiation originating from other types of signals such as emanating from naval ships (corrosion currents, electric circuits, generators, moving machinery) or from electric or magnetic sources located in boreholes or nearby land sources. The objective of these measurements could range from detailed exploration of the subsurface conductivity structure to monitoring naval traffic or operations to determining leakage signals from subsea cables.

The subsea system usually includes an apparatus such as an magnetotelluric (MT) measurement system 100 disclosed in the Constable patent and shown in Figure 1. The MT measurement system 100 includes a body 102 having a battery pack (not shown), a data acquisition system 104, two orthogonally oriented magnetic sensors 122 and 124, and four arms 139, 140, 142, and 144, each of which includes an electrode 118, 119, 120, 121 mounted at the end thereof. The electrodes 118, 119, 120, 121 are silver-silver chloride electrodes, and the magnetic sensors 122, 124 are magnetic induction coil sensors.

The arms 139, 140, 142, 144 are five meters long and approximately 2 inches in diameter. The arms 139, 140, 142, 144 are typically formed from a semi-rigid plastic material (e.g., polyvinyl chloride or polypropylene) and are fixed to the body. The five meter length of the arms 139, 140, 142, 144 makes it difficult to store, deploy, and retrieve the MT system 100 from a surface vessel (not shown) because the arms 139,

**140, 142, 144** are fixed with respect to the body **102** (as shown in Figure 1). The arms **139, 140, 142, 144** are designed to rest on the seafloor when the MT system **100** is in place.

The body **102** is attached to a releasable concrete anchor **128** that helps the MT system **100** sink to the seafloor after deployment. The body **102** generally rests on top of the anchor **128** when it is positioned on the seafloor. The anchor **128** may be released after MT measurements have been completed so that the body **102** may rise to the surface and be retrieved by the surface vessel (not shown).

The system shown in Figure 1, therefore, consists of two orthogonal electric dipoles and two orthogonal magnetic sensors. The magnetic sensors are located proximate the power supply and the data acquisition system. Because the magnetic sensors are very sensitive so as to detect small changes in the earth's magnetic field, the magnetic sensors may also detect equivalent magnetic fields generated by current flowing from the power supply to the data acquisition system and other electrical equipment. These equivalent magnetic fields may therefore contaminate the data and must be removed from the data using digital signal processing techniques.

Moreover, the magnetic sensors are extremely sensitive to noise. Any motion of the body and/or arms of the MT system caused by sea currents or marine life moving past the MT system as well as the motion of conductive fluid around the corresponding sensor can be detected. These fluctuations in the magnetic field are also recorded by the magnetic sensors and must be removed using signal processing techniques.

There is a need, therefore, for an MT system that is less sensitive to motion generated by subsea events and to equivalent magnetic fields produced by the flow of electric current from the power supply to, for example, the data acquisition system. Moreover, it would be advantageous to design a subsea MT system that is easy to store, deploy, and retrieve.

### **Summary of the Invention**

In one aspect, the invention comprises a sea-floor electromagnetic measurement device for obtaining underwater measurements of earth formations, the device

comprising: a central structure; a plurality of arms pivotally coupled to the central structure, and an electrode coupled to each of the arms and/or at least two magnetometers coupled to the arms.

In another aspect, the invention comprises a sea-floor electromagnetic measurement device for obtaining underwater measurements of earth formations, the device comprising: a central structure; a plurality of arms pivotally coupled to the central structure; and an electrode and/or a magnetometer coupled to each the arms.

In another aspect, the invention comprises a sea-floor electromagnetic measurement device for obtaining underwater measurements of earth formations, the device comprising: a central structure; at least one arm pivotally coupled to the central structure; and an electrode and/or a magnetometer, coupled to the at least one arm.

In another aspect, the invention comprises a method of electromagnetic exploration, the method comprising measuring electric fields at a selected distance from a central structure of an electromagnetic measurement system. Magnetic fields are then measured proximate the same location.

Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

#### **Brief Description of the Drawings**

Figure 1 shows a prior art MT system.

Figure 2a shows a perspective view of an embodiment of the invention.

Figure 2c shows a perspective view of an embodiment of the invention.

Figure 2b shows a top view of an embodiment of the invention.

Figure 3 shows a perspective view of a hinge according to an embodiment of the invention.

Figure 4 shows a perspective view of a hinge according to an embodiment of the invention.

Figure 5 shows a perspective view of an embodiment of the invention.

Figure 6a shows a perspective view of an embodiment of the invention.

Figure 6b shows a perspective view of an arm according to an embodiment of the invention.

Figure 6c shows a plain view of a cross section of an arm according to an embodiment of the invention.

Figure 7 shows a perspective view of an EM system according to an embodiment of the invention after the system has been deployed into the sea.

Figure 8 shows a perspective view of an embodiment of an EM system as it sinks to the seafloor.

Figure 9 shows a perspective view of an embodiment of an EM system as it ascends to the surface.

### **Detailed Description**

Figures 2a and 2b show subsea electromagnetic (EM) measurement systems according to the invention. Figure 2a shows a subsea electromagnetic (EM) measurement system 1 that comprises a central structure 2 having an electrode 3 and attached to the central structure is at least one arm 4 pivotally coupled to the central structure 2. Electrode 3 can be at any location within the central structure 2. For example, electrode 3 can be attached to the central structure 2 and located within the interior end of arm 4, as shown in figure 6b. Figure 2b shows a subsea electromagnetic (EM) measurement system 1 according to an embodiment of an invention, that comprises a central structure 2. A plurality of arms 4 is pivotally coupled to the central structure 2. An electrode 5 is coupled to each of the arms 4 proximate ends thereof, and at least two magnetometers 6 are coupled to the arms 4. The coupling 7 allows positioning the arms 4 and magnetometer 6 at substantially any angle ( $\beta$ ) with respect to each other. According to the invention arms 14 can comprise at least one electrode and/or at least one magnetometer.

Figure 2c shows a subsea electromagnetic (EM) measurement system 10 that includes at least one aspect of the present invention. The EM system 10 includes a central structure 12 that comprises electronic circuitry such as a power supply (not

shown separately), a data acquisition system (not shown separately), a microprocessor (not shown separately), and related hardware and software (not shown separately). The central structure 12 generally includes communication equipment (not shown separately) so that the EM system may be remotely activated and deactivated. Moreover, the EM system 10 may also include, for example, navigation equipment such as a global positioning system (GPS) or other equipment (not shown separately) that enables location of the EM system 10 both before and after deployment into the sea. The power supply may comprise a battery pack or any other suitable power supply known in the art. Accordingly, aspects of the invention such as the foregoing electronic components of the central structure 12 are not intended to be limiting. Furthermore, it is contemplated that the central structure is simply a connection apparatus to the plurality of arms 14. Specifically, according to an embodiment, data acquisition and signal processing is performed at a remote location such as a ship, rig or a land based station. In such an embodiment, the central structure acts to connect the arms and receive signals from sensors for transmission to the remote location. The transmission can be via cable connected to the central structure or via wireless transmission.

A plurality of arms 14 (generally four as shown in Figure 2c) are pivotally coupled to the central structure 12 using, for example, hinges 15. The hinges 15 allows the arms 14 to pivot in any direction such that arms 14 can be arranged at any angle with respect to each other. As will be discussed below, the hinges 15 enable the arms 14 to pivot so that the EM system 10 may be easily stored aboard a surface vessel, deployed in the sea, and retrieved from the seafloor. In some embodiments, the arms 14 comprise fiberglass rods. In some embodiments, the fiberglass rods that form the arms 14 have a circular cross-section, the diameter of which is within the range of approximately 0.25 inches to 0.75 inches. For example, one embodiment comprises fiberglass rods having cross-sectional diameters of 1/2 inch while another embodiment comprises diameters of 5/8 inch.

Further, other embodiments may comprise arms having non-circular cross-sections. For example, one embodiment comprises an arm having a substantially elliptical cross-section, as shown in Figure 6c, that is adapted to minimize drag

induced by seawater flow over the arm. Generally, regardless of the shape of the arms 14, the arms 14 are preferably designed to have a minimum cross-sectional area or are selectively shaped so that drag resulting from seawater flow over the arms 14 is minimized during deployment, emplacement, and retrieval of the EM system 10.

The arms 14 may also be formed from other materials (e.g., other than fiberglass). Generally, any suitable material known in the art may be used to form the arms. For example, the arms 14 may be formed from polymers, composite materials, and other non-conductive materials. Furthermore, flexible materials such as chains or conductive materials may be used to extend the location of the sensors in order to further enhance some advantages discussed herein, such as ease of storage. Accordingly, the type of material used to form the arms 14 is not intended to be limiting.

Figure 6b shows one embodiment of the invention. The arms 14 can be nonconducting tubes with their free end 8 open permitting the entrance of sea-water. The sea-water comes into contact, for example, with an inner electrode 16A which is electrically coupled to the central structure. The free open end can be closed and opened through valves that permit the entrance or exit of water as well as isolate the interior of the nonconducting tube from the exterior sea water. Valves (19) can be pressure or electronically operated. These type of tubes, with or without valves, are easier to deploy in certain instances and cheaper to manufacture and maintain.

Moreover, electrodes 16A, 16B, 16C and 16D can be located at the any position along the entire length of the arms 14. For example, the electrodes 16A, 16B, 16C and 16D can be located at the free end 8 of the arms 14 as shown in Figure 2c . Also, according to an embodiment of the invention electrodes 16A, 16B, 16C, and 16D can be at any location between the free end of arms 14 and the central structure 2. Another embodiment according to the invention has electrodes 16A, 16B, 16C and 16D inserted opposite to the free end of arms 14 and attached to the central structure 2, as shown in figure 6b. The electrodes 16A, 16B, 16C and 16D can be coupled to the tubes by sliding them over the electrodes, reducing the amount of underwater connections and cables.

The hinges 15 may comprise a simple pinned connection as shown in Figure 3. However, the hinges 15 may also be formed according to any suitable design known in the art. One embodiment of a hinge 30 that may be used with the invention is shown in Figure 4. The hinge 30 comprises a wide attachment 32 that permits free vertical pivotal motion but distributes torsion of the hinge 30 (that may be caused by, for example, sea currents or the flow of seawater past the arm as the EM system is sinking to the seafloor or ascending to the sea surface) over a wider area. Distributing torsion over a wider area helps reduce the possibility that the hinge 30 will shear and fail. Further, the stabilized hinge 30 helps prevent additional, undesirable motion that could lead to anomalies in the measured magnetic field data when the EM system (10 in Figure 2) is emplaced and operating on the seafloor (11 in Figure 2).

Referring again to Figure 2c, an anchor 20 is releasably coupled proximate a bottom of the central structure 12. The anchor 20 provides ballast that helps the EM system 10 sink to the seafloor after the EM system 10 is deployed into the sea. The anchor 20 may be released from the EM system 10 at a selected time when, for example, a command is sent from a microprocessor (not shown) to an attachment mechanism (not shown) that releasably couples the anchor 20 to the central structure 12. The attachment mechanism may be any suitable attachment mechanism known in the art, such as that disclosed in U.S. Patent No. 5,770,945 issued to Constable.

Electrodes 16A, 16B, 16C, and 16D are generally coupled to the end of each of the arms 14. The electrodes 16A, 16B, 16C, 16D are positioned so as to form two electric dipoles in an "X" configuration, as shown in Figure 2c. For example, electrodes 16A and 16C may form a first dipole, and electrodes 16B and 16D may form a second dipole. The electrodes 16A-D are primarily used in controlled source applications to receive electrical signals in response to remote transmission sources, such as sea-vessel cable towed systems. Such applications are well known in the industry, including DC or low frequency (less than 0.1 Hz) systems, induced polarization (IP) systems for measuring resistance changes over frequency and multiple controlled source transmissions. It should be noted that although the electrodes are discussed in the context of proximate arm mounting, electrode placement near or at the central structure is also contemplated with only minor

adjustments and still achieving at least some of the advantages realized in the specific embodiments described herein.

Moreover, according to an embodiment of the invention, a magnetometer 18A, 18B is generally coupled to each of at least two of the arms 14 so as to form an orthogonal magnetic field measurement system. The arms 14 are adapted to pivot about the hinges 15 so that the electrodes 16A, 16B, 16C, 16D and the magnetometers 18A, 18B rest on the seafloor 11 when the EM system 10 is emplaced in a selected position.

It should be understood that although the system described in conjunction with a preferred embodiment having both magnetotelluric and controlled source electromagnetic measurement systems, the disclosed subject matter and the associated advantages do not require combined use of a magnetometer system and an electrode system. Specifically, a magnetotelluric measuring system having a magnetometer system without the controlled source electrode system and a system incorporating only the electrode system both benefit from the disclosed subject matter.

The arms 14 are designed to have a selected length that is great enough to position the magnetometers 18A, 18B a sufficient distance from the central structure 12 so that magnetic fields generated by the flow of current in the electrical systems of the central structure 12 are substantially undetected by the magnetometers 18A, 18B. The amplitude of the magnetic fields generated proximate the central structure 12 and measured by the magnetometers 18A, 18B is inversely proportional to the cube of the distance between the magnetometers 18A, 18B and the central structure 12. Thus, positioning the magnetometers 18A, 18B proximate the ends of the arms 14 (e.g., a distance that is generally several meters from the central structure 12) effectively eliminates the interference and "noise" generated by the magnetic fields in the central structure 12. In some circumstances attenuation of the magnetic interference signals by more than 40 dB has been observed when the recording systems were moved from the center of the structure to the arms.

According to an embodiment, the magnetometers 18A and 18B comprise  $dB/dt$  induction sensors. These induction sensors are based on the induction of an

electromotive force due to a time varying magnetic flux. Although any number of magnetometer technologies may be used, including feedback-type sensors,  $dB/dt$  induction sensors provide certain advantages including simplified construction and increased reliability. Fluxgate are also appropriate according to an embodiment of the invention. Furthermore, various magnetometer designs include different configuration to account for pressure effects to the sensor. For example, the magnetometers may be placed in an electrically conductive pressure case or internally pressure compensated. In this way, the disclosed subject matter is not limited to any particular type of magnetometer.

Positioning the magnetometers 18A, 18B proximate the ends of the arms 14 (which are generally relatively light and flexible) also adds extra mass to the ends of the arms 14 that helps ensure that the magnetometers 18A, 18B will contact and/or be partially embedded in the seafloor 11 when the EM system 10 is emplaced. Increasing the mass positioned proximate the ends of the arms 14 helps improve mechanical stability by firmly holding the arms 14 in place so that the flow of seawater or the movement of marine life past the arms 14 and magnetometers 18A, 18B does not produce additional movement of the arms 14 or EM system 10 that could introduce anomalies into recorded magnetic field data.

Another embodiment of the invention, shown in Figure 5, comprises four magnetometers 24A, 24B, 24C, and 24D each disposed proximate the end of each of the arms 14 so as to form two orthogonal pairs of magnetometers. The use of two pairs of magnetometers 24A, 24B, 24C, 24D provides an extra orthogonal magnetic field measurement system that enables recording of redundant data, thereby increasing the reliability of the recorded data and providing an additional set of measurements that may be useful to decrease and/or filter out noise, anomalies, and the like.

An embodiment of mounting a magnetometer to an arm is shown in Figure 6a. The magnetometer 26A is coupled to the arm 14 using a flexible cable 27A. This embodiment further isolates the magnetometer 26A from the motion of the arm 14 and the EM system (10 in Figure 2c) so that the magnetometer 26A is substantially completely dynamically decoupled from other elements of the EM system (10 in

Figure 2c). However, the cable 27A has a stiffness selected so that the magnetometer 26A substantially maintains the desired geometric relationship. A similar arrangement may be used with other magnetometers (e.g., magnetometer 18A shown in Figure 2c) coupled to other arms.

Moreover, each magnetometer can include a tiltmeter for measuring the inclination of each magnetometer with respect to the seafloor.

Figure 7 shows a view of the embodiment shown in Figure 2c as the EM system 10 is being deployed into the sea. The arms 14 generally pivot downward about the hinges 15 because of gravity when the EM system 10 is lifted to an elevated position above the sea surface. A crane (not shown) then lowers the EM system 10 into the sea and releases the EM system so that it may sink to a selected position on the seafloor (11 in Figure 2c).

Figure 8 shows a view of the EM system 10 as it sinks to the seafloor (11 in Figure 2c). The arms 14 generally pivot upward about the hinges 15 (e.g., because of the drag exerted by the passage of the arms through the seawater) so that the central structure 12 and anchor 20 precede the arms 14 to the seafloor (11 in Figure 2c). The ability of the arms 14 to pivot reduces a “drag footprint” of the EM system 10 in that the arms 14, in the upward pivoted or “folded” position, are generally subject to less drag (e.g., than if they were fixedly connected to the central structure 12 and not able to pivot). The drag reduction reduces the time it takes for the EM system 10 to sink to the seafloor (11 in Figure 2c). As shown in Figure 2c, when the central structure 12 and anchor 20 come to rest on the seafloor 11, the arms 14, including the electrodes and magnetic sensors, pivot downward about the hinges 15 so that they lay on the seafloor 11 and form the “X” shaped dipole pair.

After electromagnetic (EM) measurements have been completed, the anchor (20 in Figure 2c) is separated from the central structure (12 Figure 2c) at a selected time as described above. The central structure (12 Figure 2c) comprises a plurality of flotation devices (22 Figure 2c) coupled thereto so that the EM system (10 Figure 2c) is buoyant after the anchor (20 Figure 2c) has been released. The flotation devices (22 Figure 2c) may contain air or any other suitable gas or buoyant material. Accordingly,

after the anchor (20 Figure 2c) has been released, the EM system (10 Figure 2c) begins to ascend to the surface of the sea. As shown in Figure 9, the arms 14 generally pivot downward about the hinges 15 as the EM system rises to the sea surface. Once again, the reduction in drag produced by the ability of the arms 14 to pivot at the hinges 15 reduces the ascent time of the EM system 10 and may reduce the number and/or size of the flotation devices 22 required to lift the EM system 10 to the surface. Once at the surface, the EM system 10 may be retrieved by a surface vessel (not shown) so that data may be retrieved and the like.

Advantageously, the EM system described herein is easy to store, deploy, and retrieve because the arms of the EM system can pivot relative to the central structure. The EM system provides a stable magnetic field measurement platform that is less susceptible to anomalies caused by sea currents and marine life because the magnetic sensors are substantially dynamically decoupled from the central structure. Accordingly, the EM system described herein may produce more accurate measurements of formation resistivity and/or conductivity and may ease the process of subsea electromagnetic exploration.

Finally, the system and method described herein can be used not just for electromagnetic measurements, but all kinds of controlled source electromagnetics, marine DC resistivity or marine impedance measurements. It is also applicable to to earthquake monitoring for remote sites that are doing underwater surveillance for marine activity or for marine monitoring applications.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

## CLAIMS

1. A sea-floor electromagnetic measurement device for obtaining underwater measurements of earth formations, the device comprising:
  - a central structure;
  - a plurality of arms having a first end and a second end, the second end pivotally coupled to the central structure, the first end being a free end; and
  - at least one of an electrode and a magnetometer coupled to each the arms.
2. The measurement device of claim 1, wherein the plurality of arms comprises four arms arranged so as to form a cross dipole pattern.
3. The measurement device of claim 1, wherein each electrode is disposed proximate the first end of each arm.
4. The measurement device of claim 1, wherein the at least two magnetometers are disposed proximate the first ends of adjacent arms.
5. The measurement device of claim 4, wherein the at least two magnetometers are coupled to the arms by cables.
6. The measurement device of claim 4, wherein the magnetometers are positioned a selected distance from the central structure so that magnetic fields produced by electric currents in the central structure substantially do not affect the measurements made by the magnetometers.
7. The measurement device of claim 1, wherein each of the arms comprises a cross-section adapted to minimize drag when the measurement device is deployed in and retrieved from the sea.
8. The measurement device of claim 1, wherein the electrodes and the magnetometers are substantially dynamically decoupled from the central structure.

9. The measurement device of claim 1, wherein each arm comprises a tube having a first and a second end, the second end pivotally coupled to the central structure and the first end comprising an opening to allow the entrance of ocean water.
10. The measurement device of claim 1, wherein the magnetometers do not comprise feedback winding.
11. The measurement device of claim 1, further comprising electronic circuitry coupled to the central structure, the electronic circuitry adapted to control the measurement system and to record electric field measurements of the electrodes and magnetic field measurements of the magnetometers.
12. A method of undertaking sea-floor electromagnetic measurements, the method comprising:
  - measuring electric fields at a location a selected distance from a central structure of a electromagnetic measurement system; and
  - measuring components of magnetic fields proximate the same location.
13. The method of claim 12, wherein the electric fields are cross dipole electric fields.
14. The method of claim 13, wherein the components of magnetic fields are orthogonal.



Application No: GB 0312127.4  
Claims searched: 1-14

15

Examiner: S M Colcombe  
Date of search: 9 December 2003

## Patents Act 1977 : Search Report under Section 17

### Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	12-14	EP 0913555 A2	(HALLIBURTON) Whole document.
X	12-14	US 5770945	(UNI. CALIFORNIA) Whole document.
A		GB 1118509	(CENT. NAT. RECH. SCI.)
A		EP 0590795 A2	(RAYTHEON)

### Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>6</sup>:

G1N

Worldwide search of patent documents classified in the following areas of the IPC<sup>7</sup>:

G01V

The following online and other databases have been used in the preparation of this search report:

WPI, EPODOC, JAPIO, OPTICS